

# Yb:YAG MOPA System and Non-linear Frequency Conversion for Remote Sensing Applications

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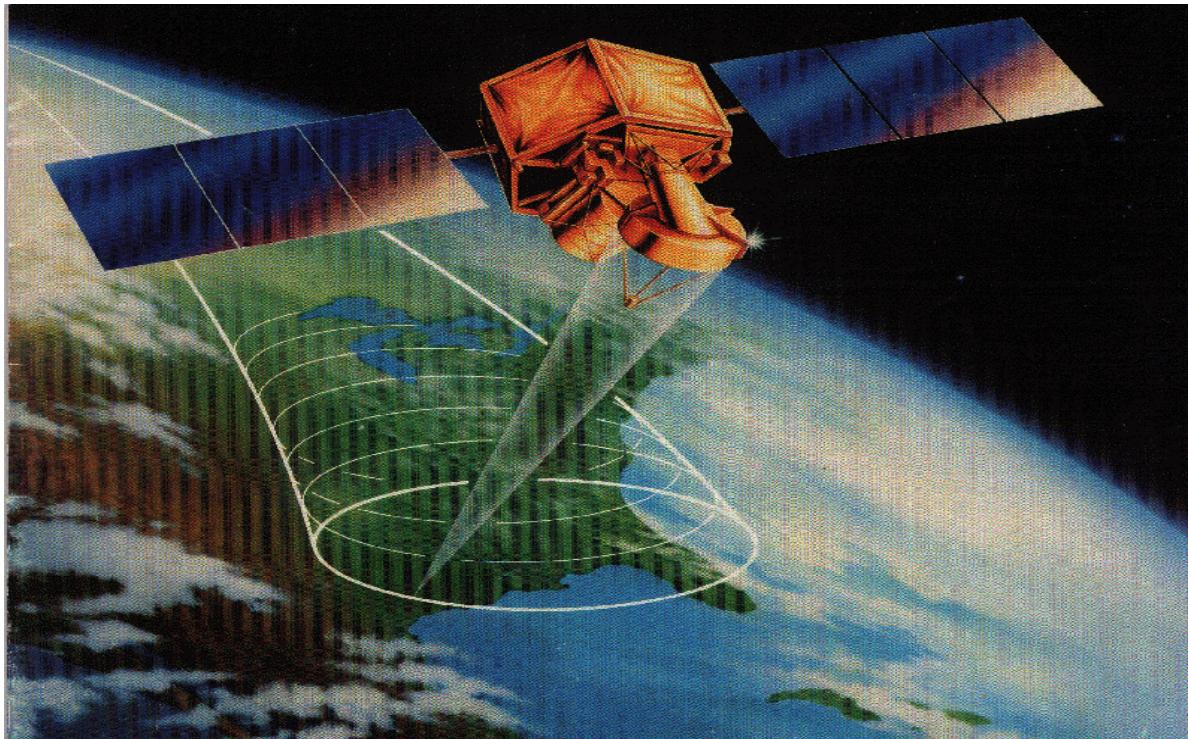
Sponsors: NASA (ATIP Program)  
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# Global wind velocity sensing

- **Measurement specifications**
  - 100 km hor. res., 1 km ver. res. , 1 m/s velocity accuracy, eye safety.

## Laser transmitter specifications for wind sensor

- Energy: 2J/pulse
- Repetition rate: 10 Hz
- Pulse width:  $\sim 1\mu\text{s}$
- Linewidth : 1 MHz
- Satellite altitude :400 km
- $\lambda > 1.4 \mu\text{m}$

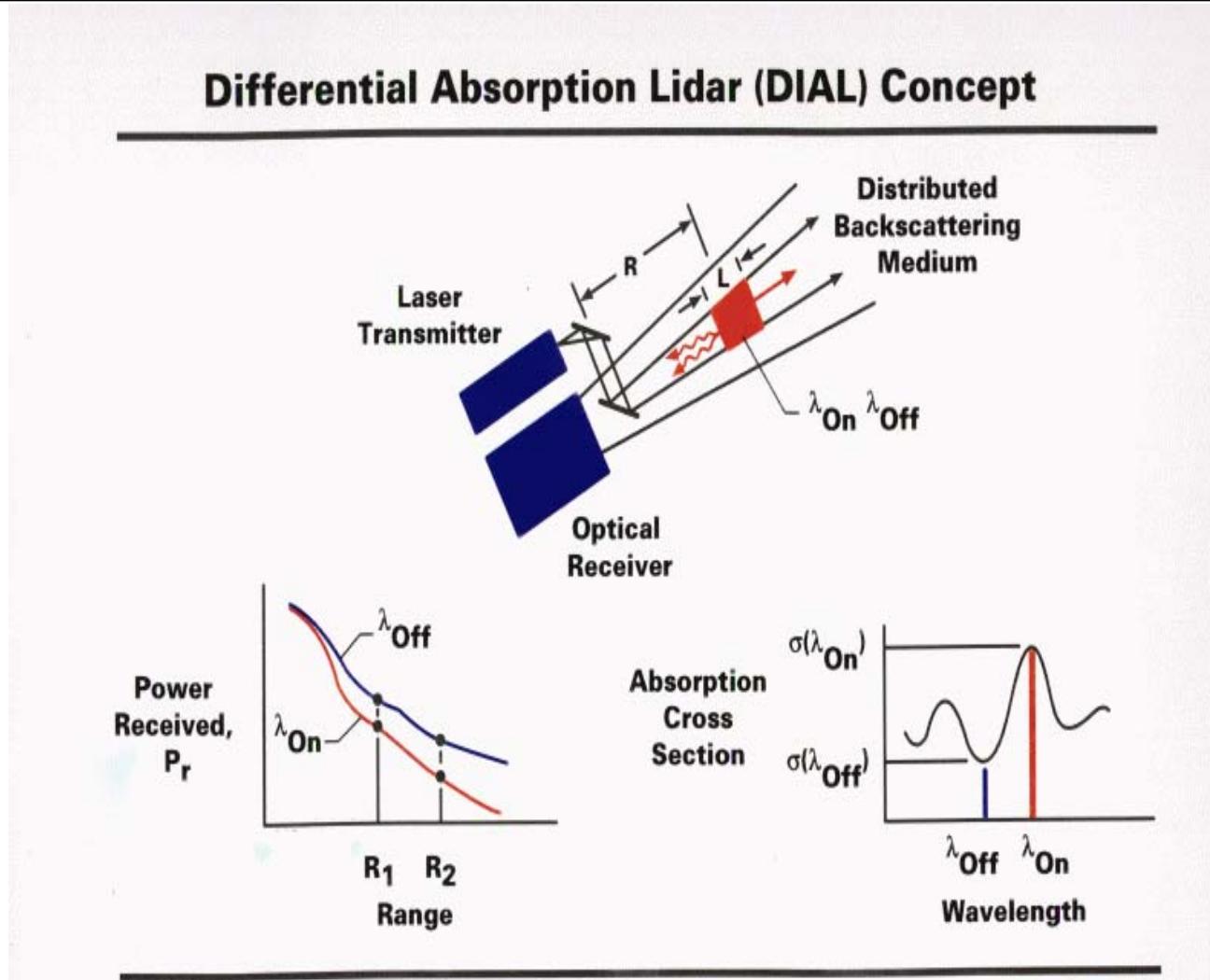


# DIAL based ozone detection

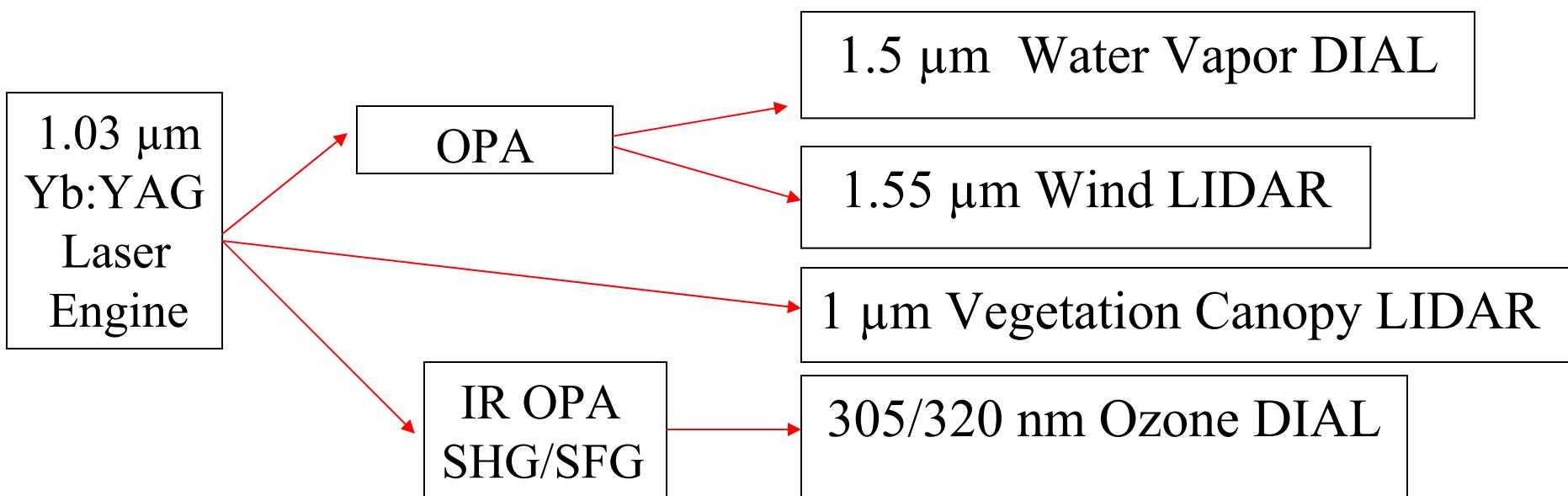
- Tropospheric Ozone( $O_3$ ),  $NO_2$ ,  $SO_2$  detection
  - 1-2 km vertical resolution.

## Laser transmitter specifications for Ozone detector

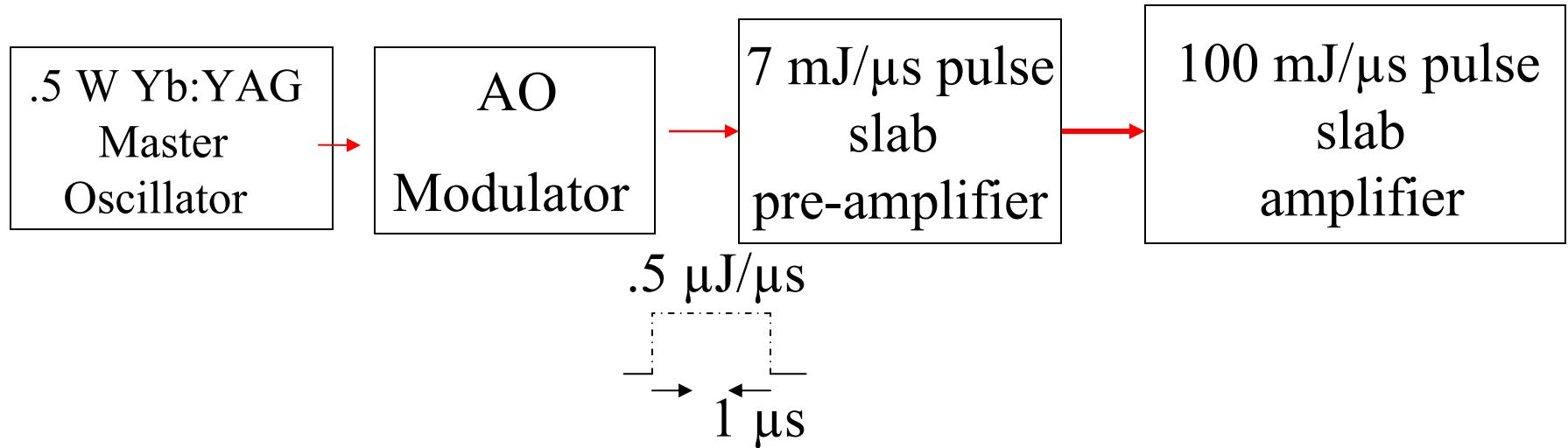
- Energy: 0.5 J/pulse
- Repetition rate: 10 Hz
- Pulse width:  $\sim 1\mu s$
- $\lambda = 305 \text{ nm}, 320 \text{ nm}$



# Applications for Yb:YAG Laser Engine



# 1.03 $\mu\text{m}$ Yb:YAG Laser Engine



Master Oscillator

Power Amplifier (MOPA)

Advantages

- Scalability
- Good beam quality
- Coherence

# Outline

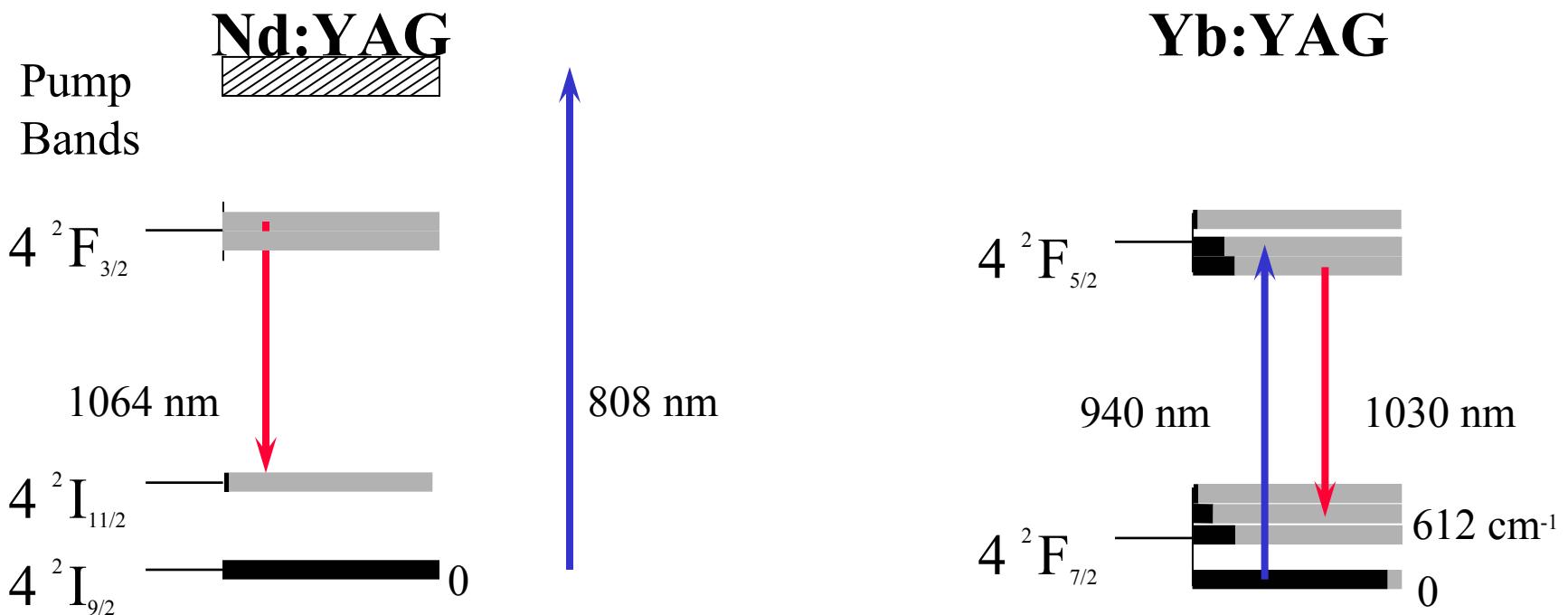
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- Motivation & Approach
- Yb:YAG MOPA
  - 7 mJ Pre-amplifier Design
  - 100 mJ Amplifier Design
- Nd:YAG MOPA
- Non-linear Frequency Conversion Module
  - Design and Test of PPLN Optical Parametric Amplifiers
  - Testing of LBO based Second Harmonic Generation.

# Why Yb:YAG ?

1. Smaller pump quantum defect, means higher efficiency is possible.

$$\frac{\lambda_{p\_808nm}}{\lambda_{l\_1064nm}}(Nd:YAG) < \frac{\lambda_{p\_940nm}}{\lambda_{l\_1030nm}}(Yb:YAG)$$



# Why Yb:YAG ?

2. Long upper state lifetime ( 1msec) means fewer pump laser diodes are needed to store the same energy.
3. Higher Energy Storage density.

Yb:YAG has 10 times smaller  $\sigma_e$  compared to Nd:YAG

$$g_0 l = \Delta N \sigma_e l < 3$$

because of the onset of parasitic oscillations

$$\frac{E_{stored}}{V} = g_0 l F_{sat}$$

# Why 1 $\mu$ s Pulses?

1. Transform limited 1 MHz line-width required for 1 m/s global wind velocity resolution.

2.  $F_{\text{sat}} = \text{Saturation Fluence} = 9.6 \frac{\text{J}}{\text{cm}^2}$

$$F_{\text{damage}_{\mu\text{s}}} = \text{Optical damage fluence for } \mu\text{s pulses} = 100 \frac{\text{J}}{\text{cm}^2}$$

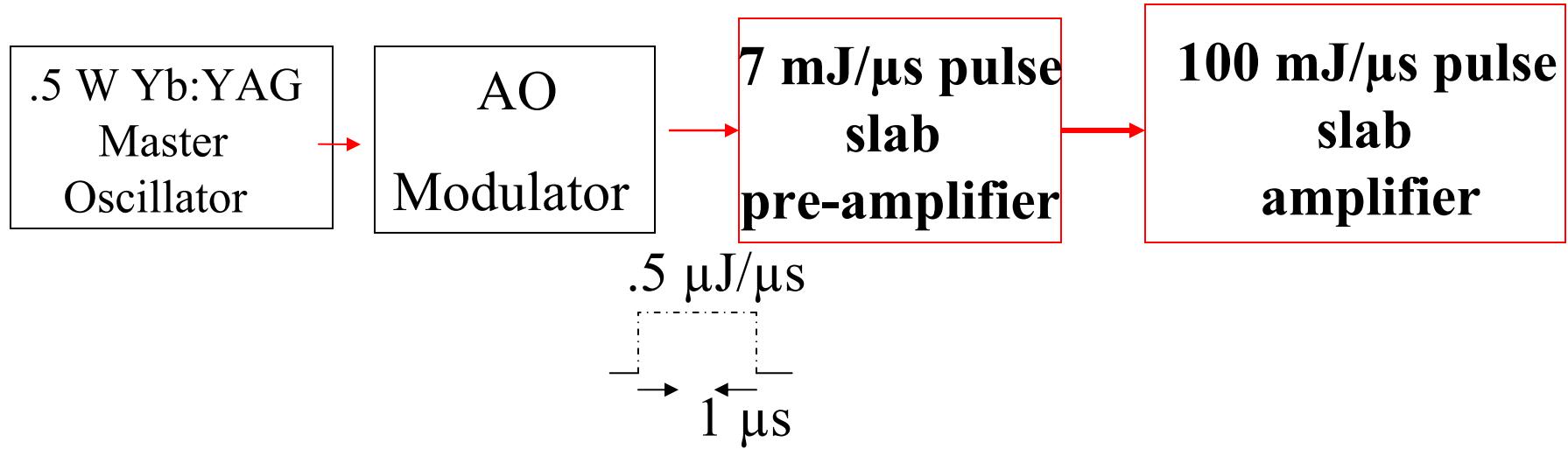
$$F_{\text{damage}_{10\text{ns}}} = \text{Optical damage fluence for 10 ns pulses} = 10 \frac{\text{J}}{\text{cm}^2}$$

Therefore,  $F_{\text{sat}} < F_{\text{input}_{\mu\text{s}}} < F_{\text{damage}_{\mu\text{s}}}$

for efficient extraction of stored energy



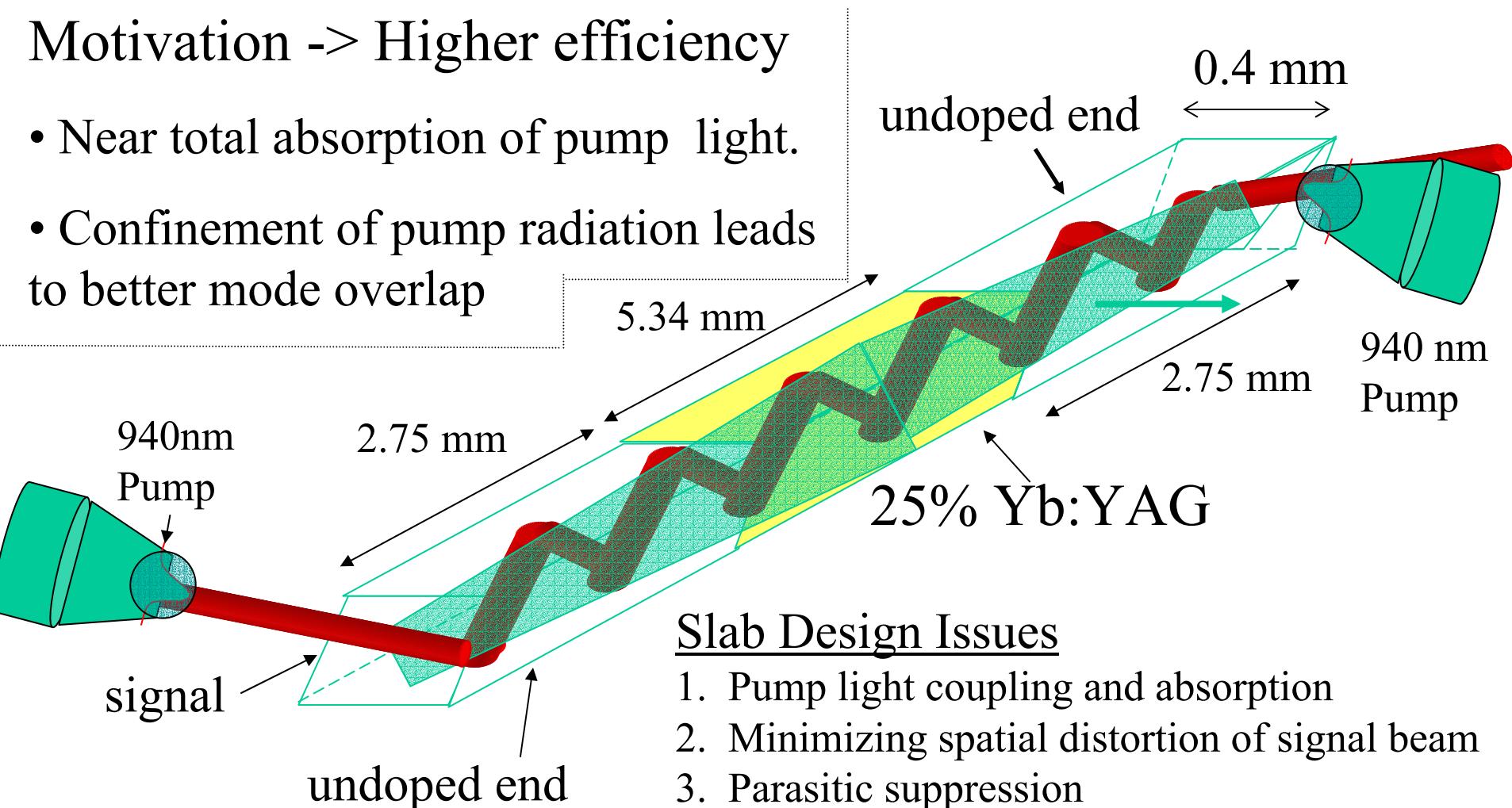
# 1.03 $\mu\text{m}$ Yb:YAG Laser Engine



# End-pumped Slab Amplifier Approach

Motivation -> Higher efficiency

- Near total absorption of pump light.
- Confinement of pump radiation leads to better mode overlap

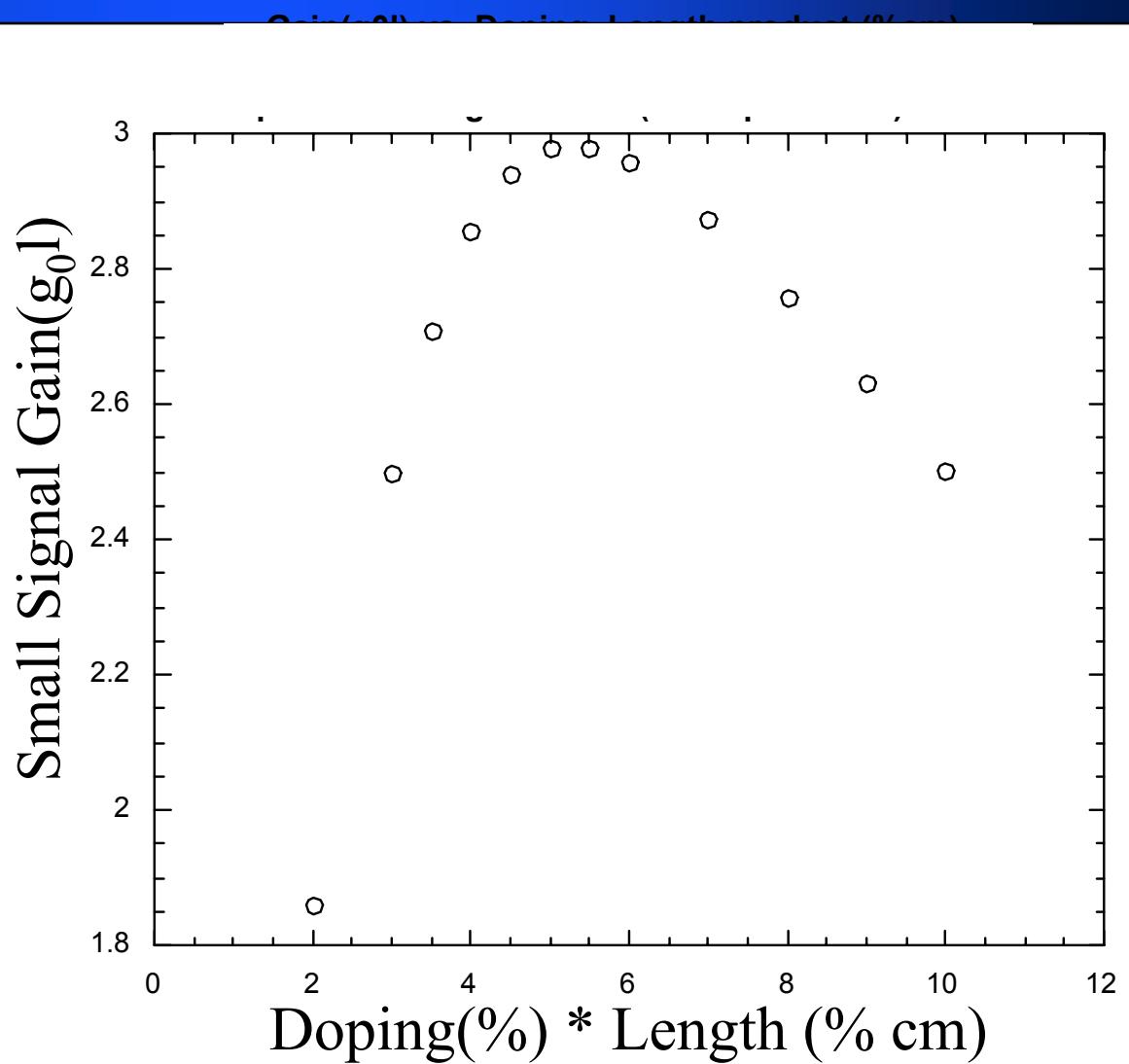
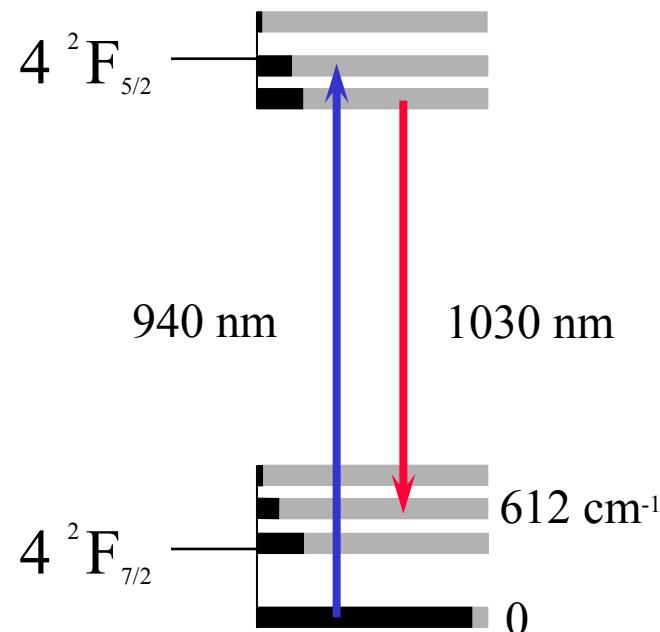


## Slab Design Issues

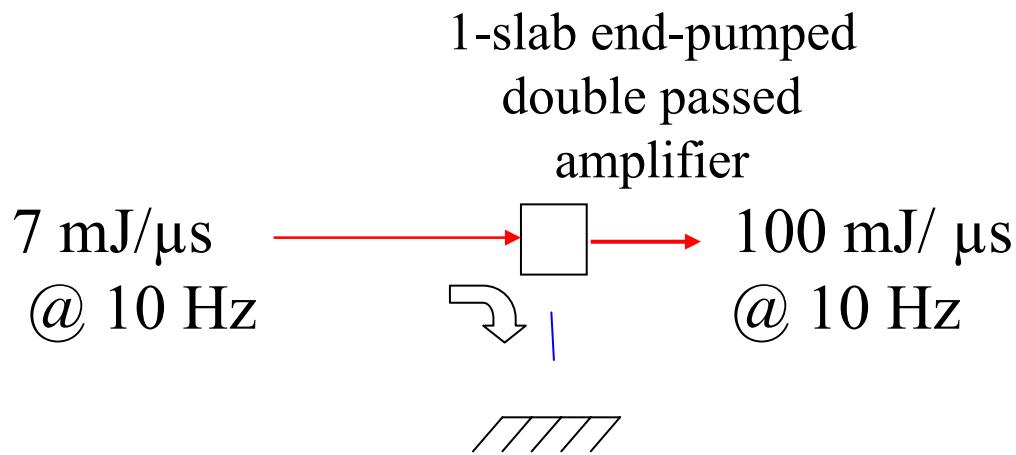
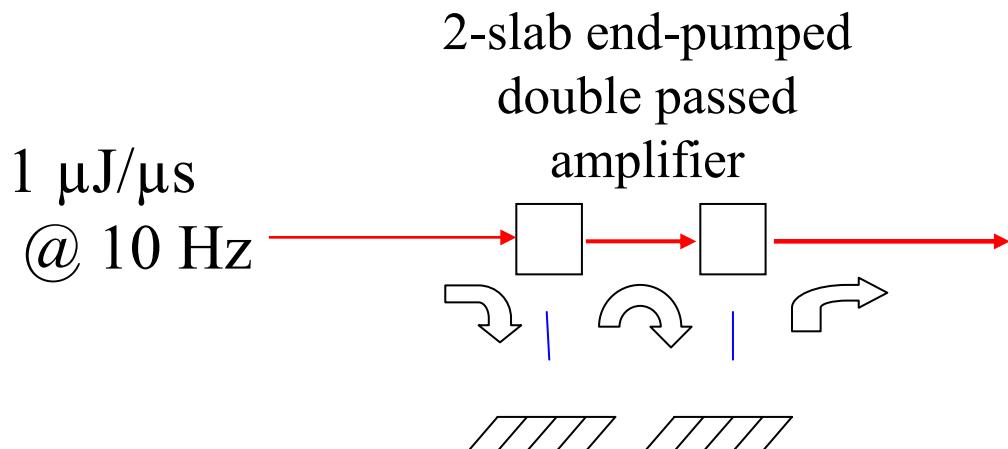
1. Pump light coupling and absorption
2. Minimizing spatial distortion of signal beam
3. Parasitic suppression

# Optimization of Pump Absorption

**Yb:YAG**

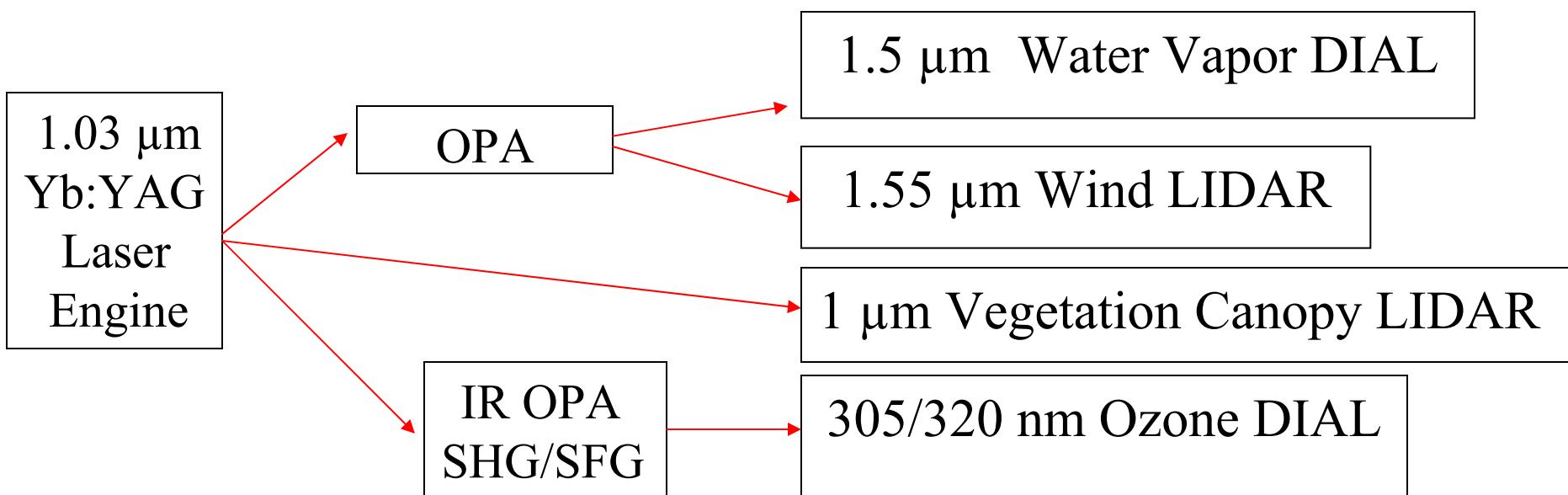


# 7 mJ/ $\mu$ s and 100 mJ/ $\mu$ s Amplifier Modules Schematic



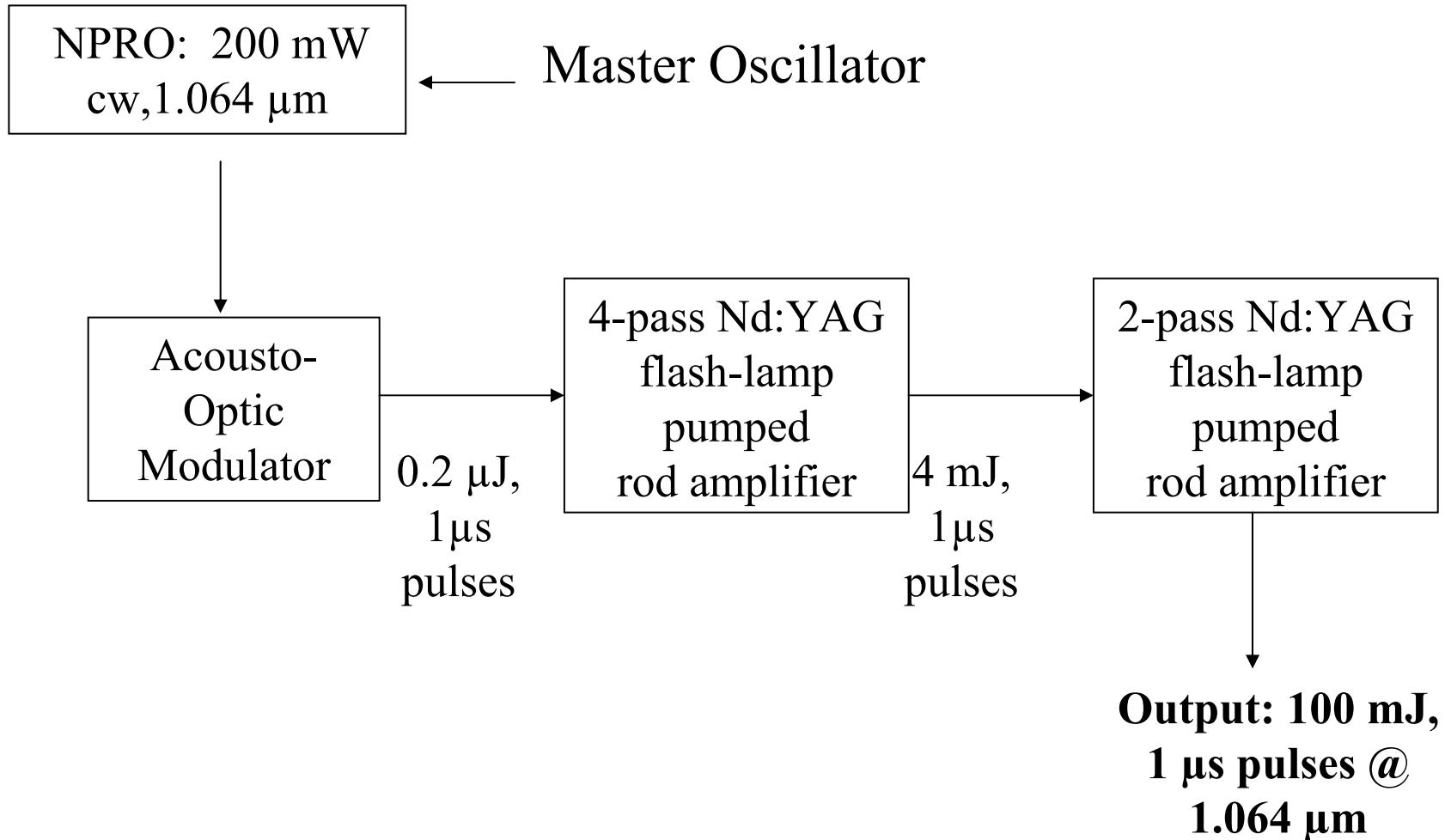
Pump LD's are operated at 1 % duty cycle

# Applications for Yb:YAG Laser Engine



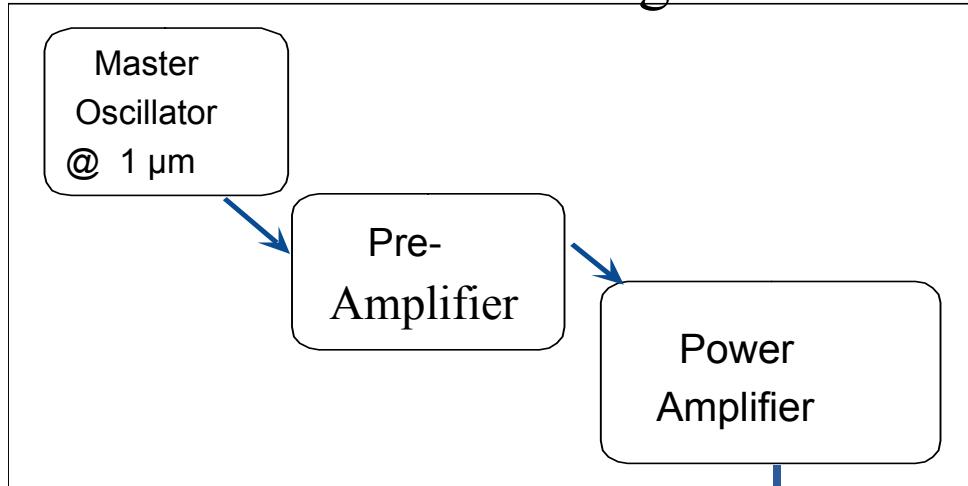
# Nd:YAG MOPA Test-bed

## for Nonlinear Frequency Conversion



# 1.55 $\text{Om}$ MOPA System Schematic

## 1.03 $\text{um}$ Laser Engine



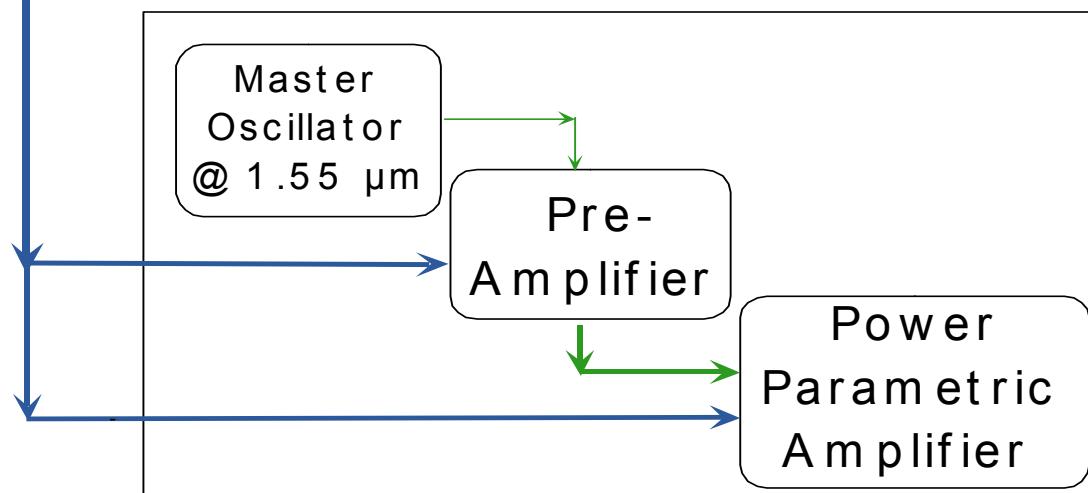
MOPA approach advantages

- Scalability
- Good Beam Quality
- Coherent

Parametric conversion

Parametric approach  
advantages

- High conversion efficiency
- Narrow linewidth



# Non-linear Frequency Conversion for Global Wind Sensing

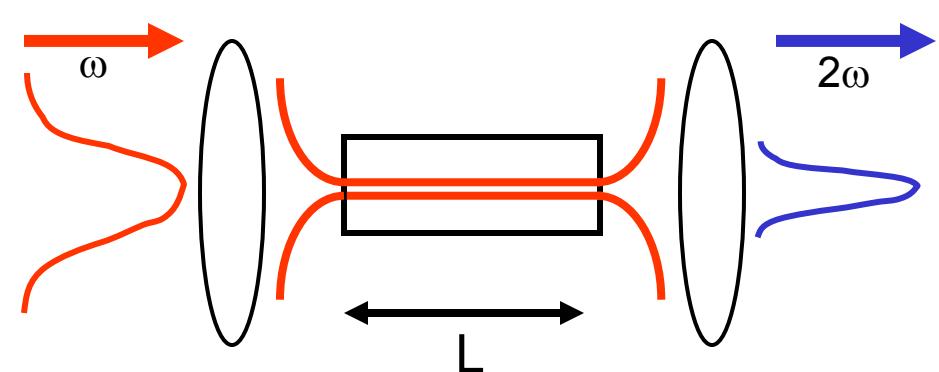
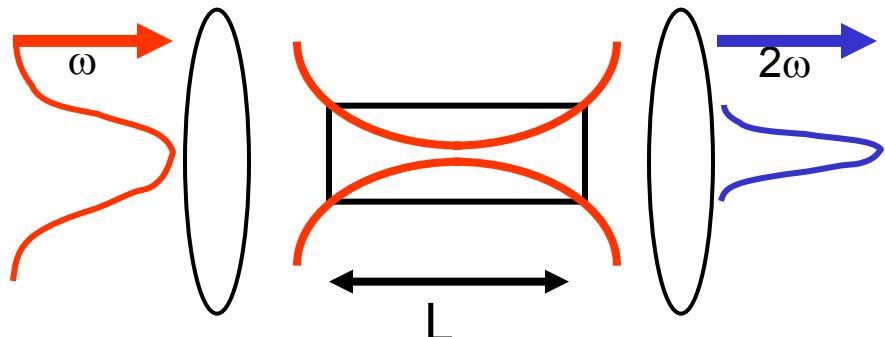
Goal: Achieve high pulse energy radiation in 1.5  $\mu\text{m}$  eye-safe band.

*Possible materials for parametric amplification*

Materials	$d_{\text{eff}}$ (pm/V)	Optical damage threshold, $J_{\text{th}}$ ( $\text{J}/\text{cm}^2$ ) for 1 $\mu\text{s}$ pulses	$\text{FOM} = d_{\text{eff}}^2 * J_{\text{th}}$
PPKTP	8.7	40	3041
KTA	2.5	107	670
<b>PPLN</b>	<b>17.2</b>	<b>30</b>	<b>8875</b>
PPLT	8.8	41	3213

We choose PPLN because it has the best Figure of Merit

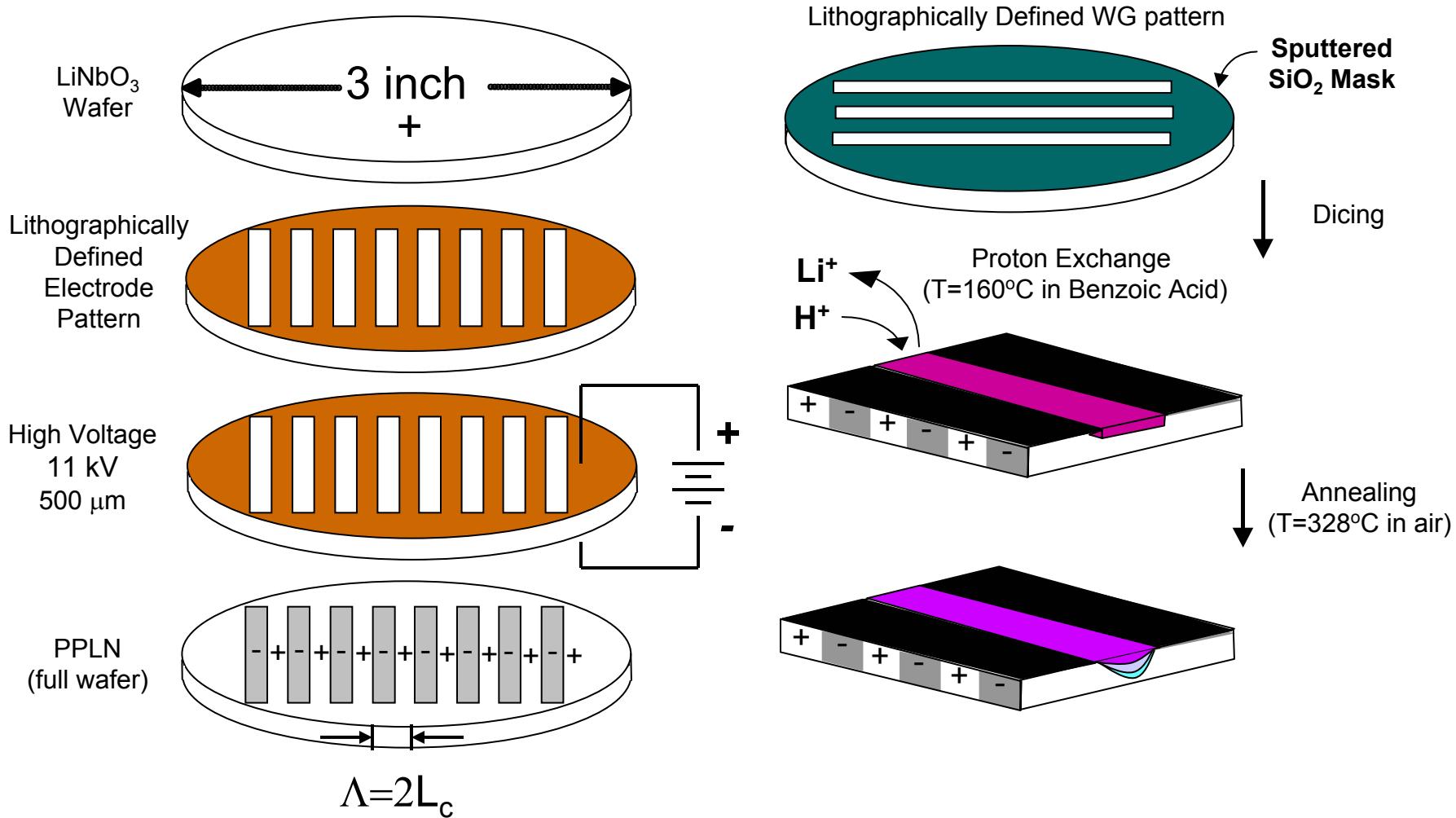
# Bulk vs Waveguide Interactions



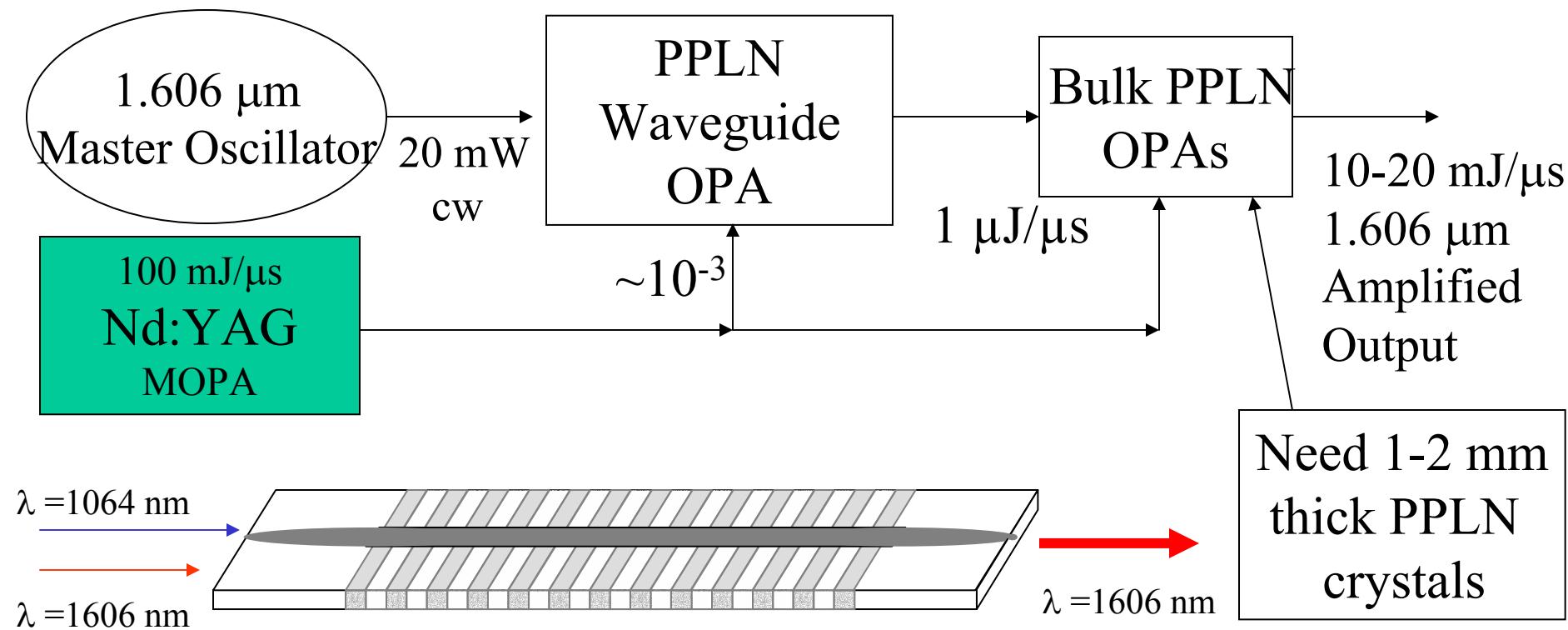
- Diffraction leads to intensity variation along length  $L$
- Mixing efficiency  $\propto L$
- Transverse variation of power produces non-uniform conversion (peak sees stronger depletion than wings)

- Small (intense) spot maintained over entire length
- Mixing efficiency  $\propto L^2$
- Waves interact as complete entities (eigenmodes) - no transverse variation of efficiency
- Fiber pigtailing possible

# APE PPLN Fabrication Process

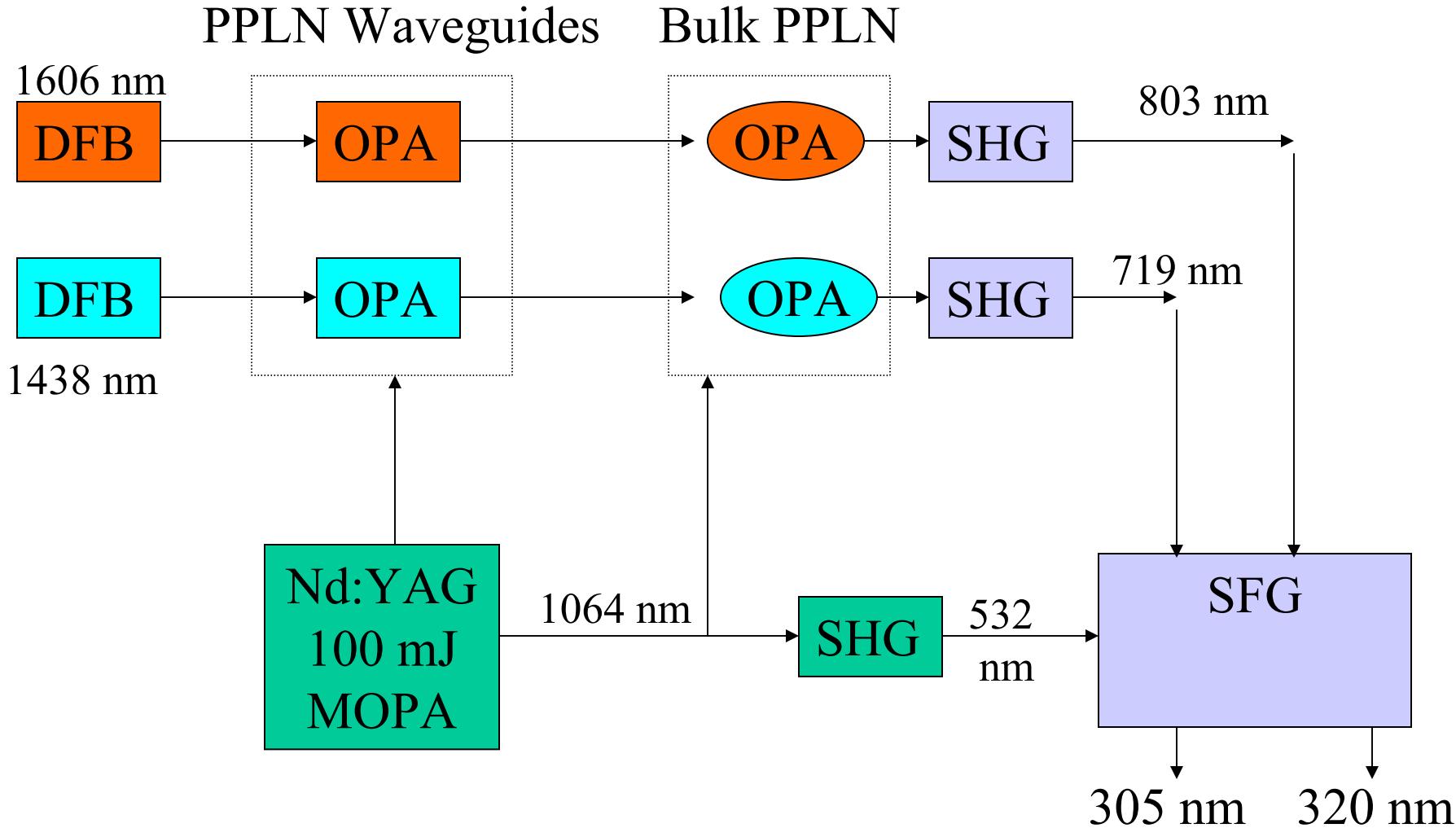


# Optical Parametric Amplifier (OPA) System Schematic



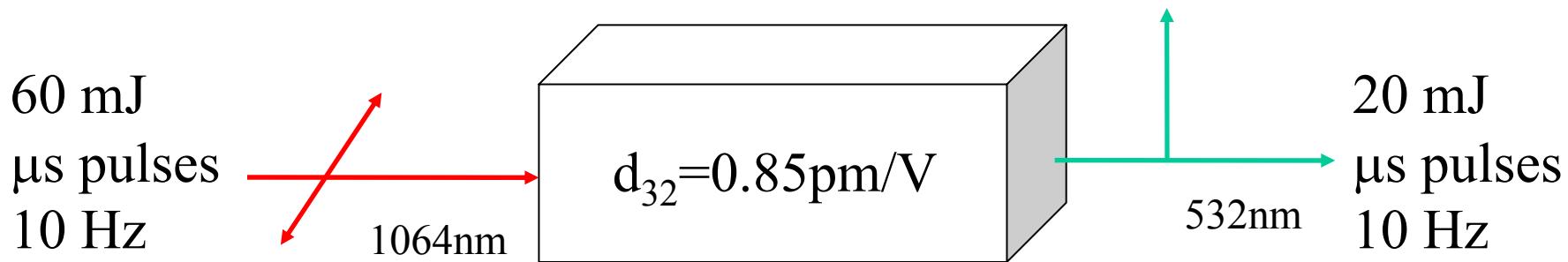
Preliminary expts, which have led to an understanding of the dispersion in PPLN waveguides  
At the 3 μm idler wavelength, show 4-5 dB gain. Improved devices involving longer  
interaction lengths are expected to yield > 20 dB gain at signal wavelength.

# Nd:YAG MOPA Based Nonlinear Frequency Conversion Module Schematic for Ozone DIAL



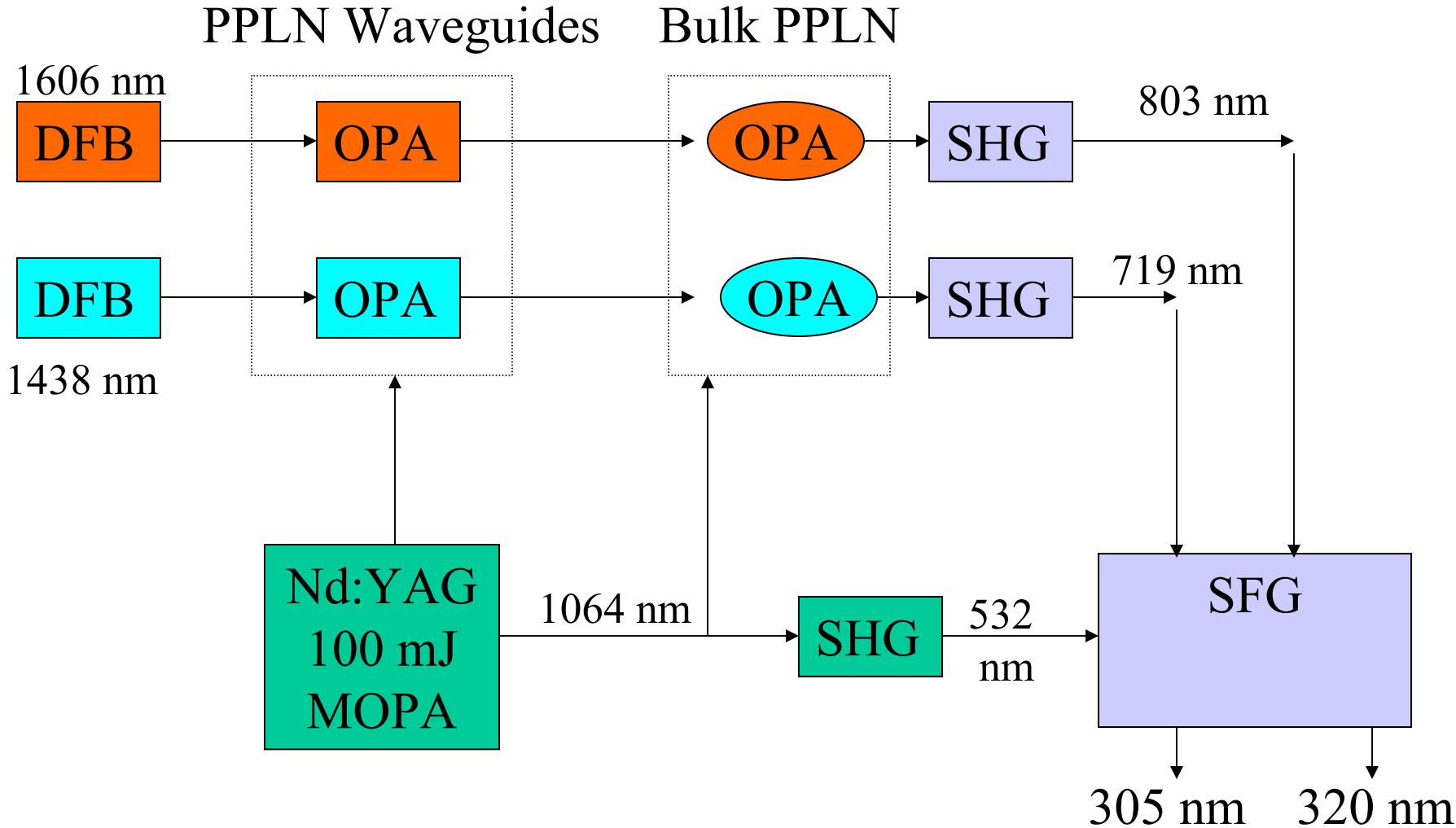
# Experimental SHG results in LBO

- Transparency from 160nm to 2600nm
- High Damage Threshold ( $>25\text{J/cm}^2$  for near IR wavelengths)
- Availability in lengths up to 40mm
- Exhibited high efficiencies in similar experiments
- Non-hygroscopic



Measured conversion efficiency(30%) is close to theoretical efficiency.

# Nd:YAG MOPA Based Nonlinear Frequency Conversion Module Schematic for Ozone DIAL



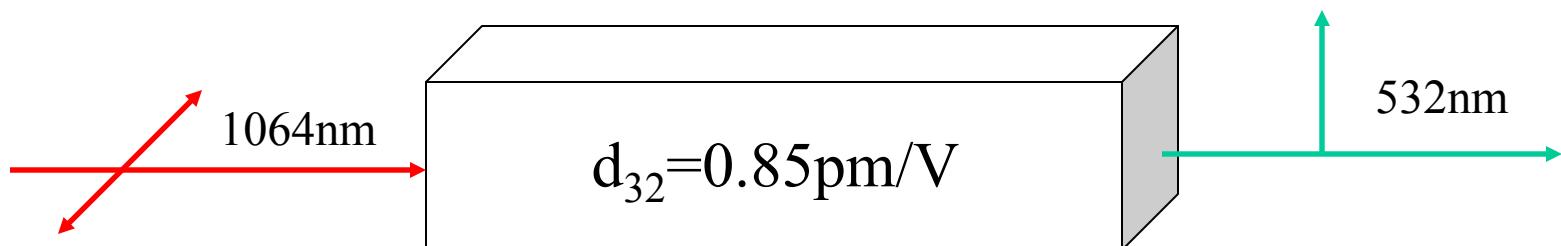
# Conclusion

- Yb:YAG  $\mu$ s pulse based MOPA architecture has potential to serve as laser engine for nonlinear conversion for remote sensing applications.
- Demonstrated 100 mJ/ $\mu$ s Nd:YAG MOPA.
- Initial PPLN waveguide OPA's led to an understanding of waveguide dispersion and 4-5 dB gain.
- Pulse energy scaling of PPLN OPA's by increasing aperture size will be key to meeting wind sensing application requirements.
- Further non-linear conversion to UV is key to meeting Ozone DIAL requirements.

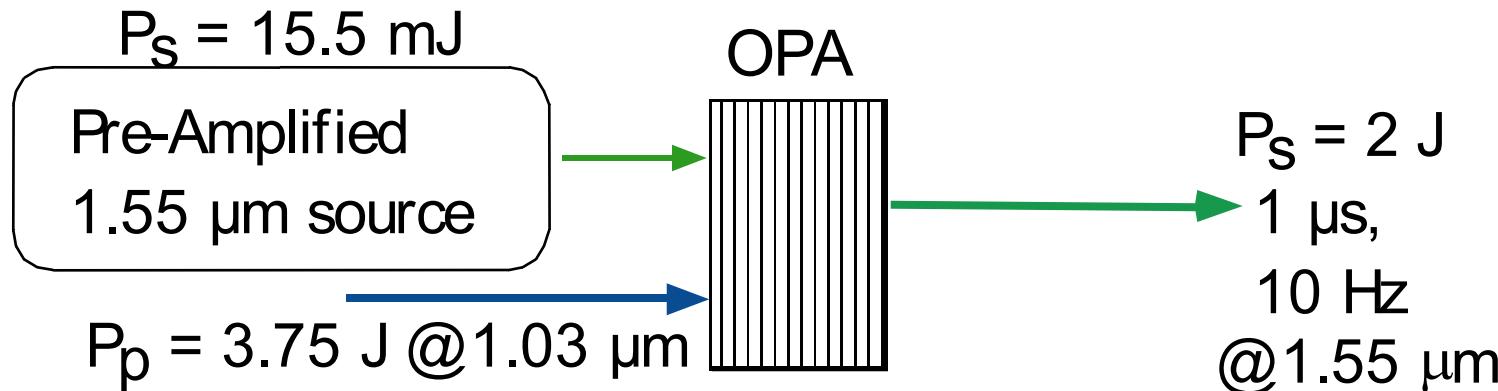
The remaining slides are  
miscellaneous, and are meant for  
providing additional details on  
possible questions.

# SHG Using LBO

- Lithium Triborate (LBO) is widely used and has exhibited high SHG conversion efficiency (>70%)
- Type I, Non-critical phase-matching (NCPM) reached at 148°C
  - Wide acceptance angle (>52 mrad-cm)
  - No Poynting vector walkoff
  - Can access the highest nonlinear coefficient.



# Power OPA Design Parameters



Thickness = 3 mm, Width = .76 cm, Length = 2.3 cm

Beam area =  $18 \text{ mm}^2$

Ellipticity of beam = 4:1

Optical Damage Fluence for 1  $\mu\text{s}$  pulses >  $30 \text{ J/cm}^2$

# Lithium Triborate(LBO)

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Material of choice for Second harmonic generation (SHG) of Nd:YAG MOPA output.

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## Relevant Properties

- Transparency from 160nm to 2600nm
- High Damage Threshold ( $>25\text{J/cm}^2$  for near IR wavelengths)
- Availability in lengths up to 40mm
- Exhibited high efficiencies in similar experiments
- Non-hygroscopic

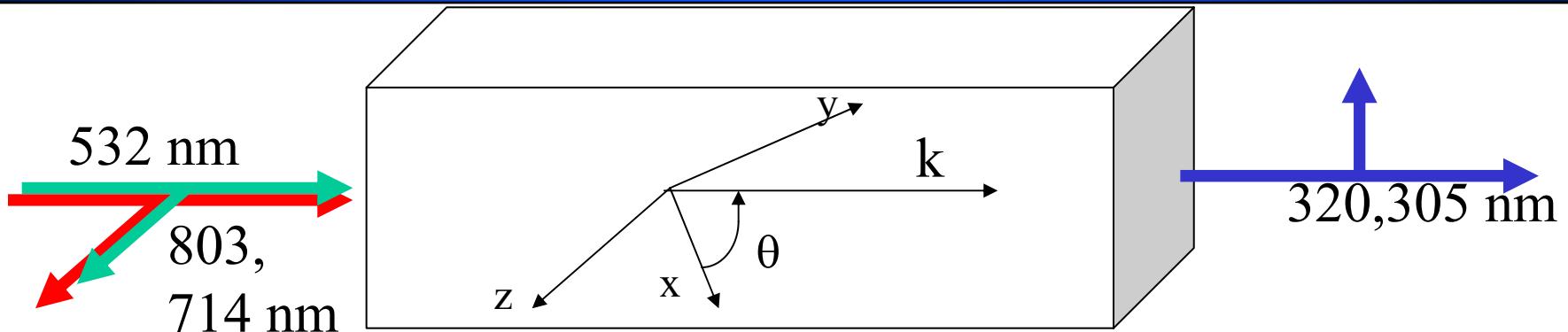
# Theoretical SHG Conversion Efficiency

- 0.5 mm spot size used in model
- 0.498 mrad half angle (1/2 the tolerance for 4cm crystal)
- Fluence ~ 50% of Damage fluence limit

$\lambda$	Peak Input Fluence	Input Pulse Energy	Output Pulse Energy (mJ)	Conversion Efficiency
1064nm	17.66 J/cm <sup>2</sup>	50mJ	35mJ	
532nm	0	0	15mJ	~ 30%

- Values estimated for non-coated crystal
- Input values from 50% of MOPA Output

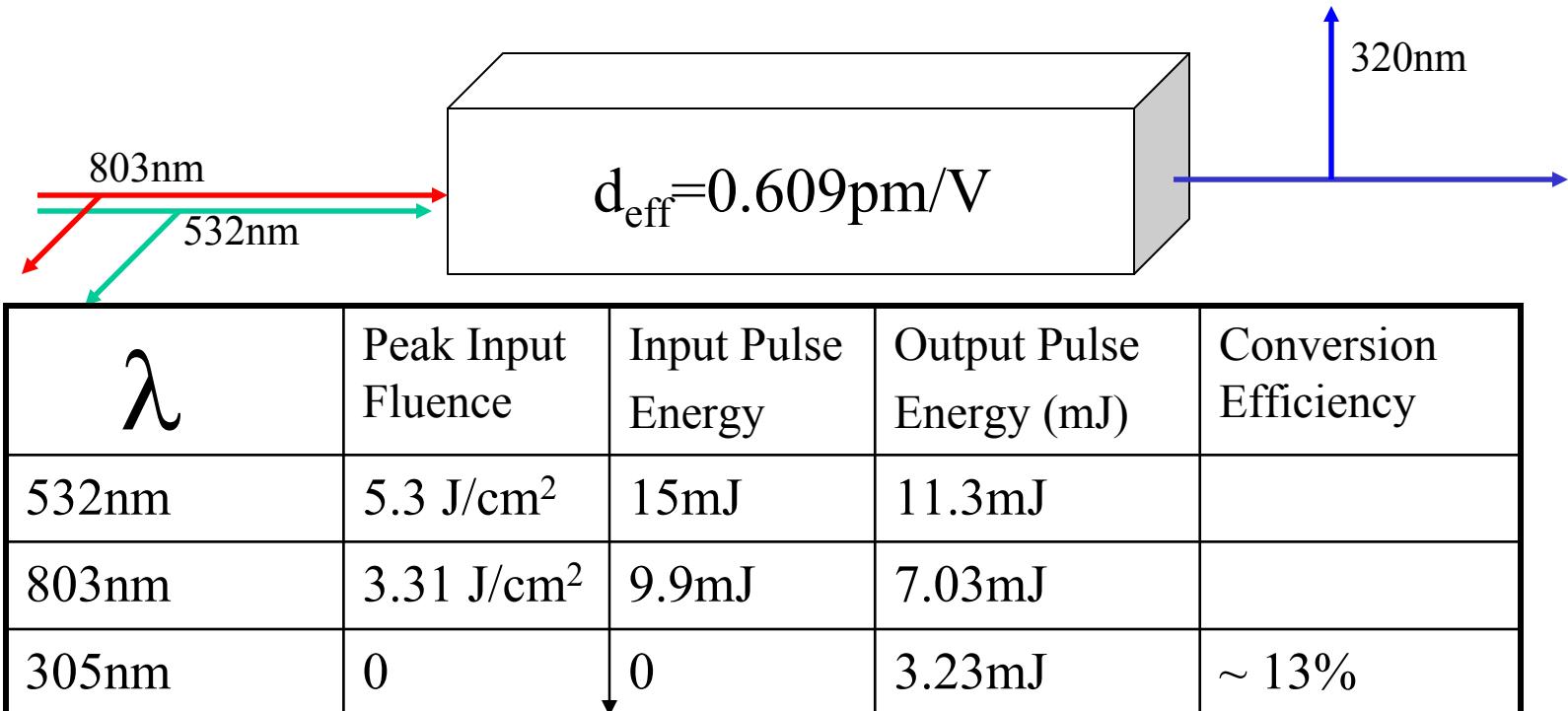
# Sum Frequency Generation Design Schematic



- Type I birefringent phase-matching scheme
- Phase-matching condition satisfied by angle tuning
  - Poynting Vector Walkoff
    - Reduces conversion efficiency
    - Affects beam profile
  - Acceptance angle significantly reduced

# Mixing of 532nm and 803nm

- Acceptance angle drops to  $\sim 1\text{ mrad}\cdot\text{cm}$
- Effective nonlinear coefficient =  $0.609 \text{ pm/V}$
- Walkoff angle 17.19 mrad
- 0.5 mm beam diameter  $\rightarrow 0.49 \text{ mrad half-angle}$
- Input Fluence < 1/3 damage threshold



# Mixing of 532nm and 719nm

- Acceptance angle drops to 2.07 mrad-cm
- Effective nonlinear coefficient = 0.489 pm/V
- Walkoff angle 15.86mrad
- 0.5 mm beam diameter → 0.33 mrad half-angle
- Input Fluence < 1/3 damage threshold

